

**REPORT DOCUMENTATION PAGE**Form Approved  
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)

2. REPORT DATE  
April 18, 20003. REPORT TYPE AND DATES COVERED  
Interim - 6-month — 9/22/00 — 3/22/01

4. TITLE AND SUBTITLE

InGaP/InGaAs-on-Ge Concentrator Solar Cell for Space Power Generation

5. FUNDING NUMBERS

NAS3-99174

6. AUTHOR(S)

Dr. Samar Sinharoy

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Essential Research, Inc.  
6410 Eastland Rd. Suite D  
Cleveland, OH 441428. PERFORMING ORGANIZATION  
REPORT NUMBER

NAS3-99174

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

National Aeronautics and Space Administration  
Glenn Research Center  
21000 Brookpark Rd.  
Cleveland, OH 4413510. SPONSORING/MONITORING  
AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Unclassified – Unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

Task 1 is now complete.

Two alternatives to the problem of limited dual-junction performance are under consideration. A change in the tunnel junction eliminates the need for reactor modification, which is the other alternative. Changing the tunnel junction has been incorporated into the design of the dual-junction cell and the cell will be processed during the next reporting period.

20010427 007

14. SUBJECT TERMS

Space Power; photovoltaics; Indium Gallium Phosphide; Concentrator Solar Cells

15. NUMBER OF PAGES  
3

16. PRICE CODE

17. SECURITY CLASSIFICATION  
OF REPORT

Unclassified

18. SECURITY CLASSIFICATION  
OF THIS PAGE

Unclassified

19. SECURITY CLASSIFICATION  
OF ABSTRACT

Unclassified

20. LIMITATION OF ABSTRACT

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)  
Prescribed by ANSI Std. Z39-18  
298-102

# InGaP/InGaAs-on-Ge Concentrator Solar Cell for Space Power Generation

**Contract—**

NAS3-99174

**Author—**

Samar Sinharoy

**Date—**

April 12, 2000

**Contractor—**

Essential Research, Inc.  
6410 Eastland Rd.  
Suite D  
Cleveland, OH 44142

These SBIR data are furnished with SBIR rights under Contract No. NAS3-99174. For a period of 4 years after acceptance of all items to be delivered under this contract, the Government agrees to use these data for Government purposes only, and they shall not be disclosed outside the Government (including disclosure for procurement purposes) during such period without permission of the Contractor, except that, subject to the foregoing use and disclosure prohibitions, such data may be disclosed for use by support Contractors. After the aforesaid 4-year period the Government has a royalty-free license to use, and to authorize others to use on its behalf, these data for Government purposes, but is relieved of all disclosure prohibitions and assumes no liability for unauthorized use of these data by third parties. This Notice shall be affixed to any reproductions of these data, in whole or in part.

ESSENTIAL  
RESEARCH  
INCORPORATED



---

**WORK PERFORMED THIS PERIOD**

---

***Task 1—Growth and characterization of a lattice-matched passivating window for InGaP***

$\text{Al}_{0.33}\text{In}_{0.67}\text{P}$  has been chosen as the lattice-matched passivating front and back window layer of the 1.62 eV InGaP top cell. This task is now complete.

***Task 3—Growth and characterization of InGaAs tunnel junction***

In the previous report, we presented the results of a two-terminal n/p InGaP/InGaAs dual-junction cell using a p++/n++  $\text{In}_{0.2}\text{Ga}_{0.8}\text{As}$  tunnel junction. InGaAs was chosen as the tunnel junction interconnect compound since it is easily degenerately doped. air-mass zero (AM0), one-sun efficiency of this dual-junction cell was measured to be 19%, and it was found to be bottom-cell current limited. A detailed analysis of the results identified several factors that were causing performance degradation. These factors were listed in the previous report.

One important factor limiting the performance of our dual-junction cell was the use of 1.1 eV InGaAs tunnel junction, which absorbs some of the red light that the bottom cell is designed to convert. Calculations indicated that the use of a non-absorbing tunnel junction (such as 1.62 eV InGaP) would result in a 6% increase in the short circuit current ( $J_{sc}$ ) of the bottom cell. However, because of limitations in the NASA metal organic vapor phase epitaxy (MOVPE) reactor currently being used for this project, it is not possible to grow a p++ InGaP layer required for the tunnel junction. We are currently exploring two alternatives to overcome this limitation as described below.

- **Reactor modification:** The installation of a “double-dilution” line from the diethyl zinc (DEZn) precursor will allow us to increase the p-doping range from  $1 \times 10^{17}/\text{cm}^3$  (needed for base-doping) to  $1 \times 10^{19}/\text{cm}^3$  (needed for the tunnel junction). This modification should be complete in late spring or early summer of this year.
- **P++ AlGaAs/n++ InGaP tunnel junction:** This alternative eliminates the need for reactor modification, although AlGaAs is not lattice-matched to the subsequent 1.62-eV InGaP top cell structure. However, since the AlGaAs layer will be very thin (0.02  $\mu\text{m}$ ), the InGaP layer is expected to grow pseudomorphically on it, without any degradation in its crystalline quality. Another problem associated with the use of aluminum containing alloys is that they usually have a higher oxygen content, and the oxygen might act as a recombination center, causing performance degradation. Thus, our goal was to keep the aluminum content in the AlGaAs at the minimum acceptable level for the tunnel junction. After several calibration runs, we have settled on  $\text{Al}_{0.09}\text{GaAs}$ . Composition and thickness calibrations were made by ellipsometry. Photoluminescence measurement showed that the bandgap was 1.55-eV. We

were able to achieve a maximum p-doping of  $8.2 \times 10^{18}/\text{cm}^3$  in this material. Thus, it is suitable for the p++ component of the tunnel junction.

**Task 4—Fabrication and testing of two-terminal InGaP/InGaAs monolithic tandem cells on GaAs substrates.**

Figure 1 shows a schematic diagram of the current design of our dual-junction cell. The 1.1 eV bottom cell is comprised of a  $0.5 \mu\text{m}$  n+  $\text{In}_{0.2}\text{Ga}_{0.8}\text{As}$  emitter, a  $3.0 \mu\text{m}$  p  $\text{In}_{0.2}\text{Ga}_{0.8}\text{As}$  base and a  $0.05 \mu\text{m}$   $\text{In}_{0.68}\text{Ga}_{0.32}\text{P}$  window layer. The 1.62 eV top cell consists of a  $0.05 \mu\text{m}$  n+  $\text{In}_{0.68}\text{Ga}_{0.32}\text{P}$  emitter, a  $0.275 \mu\text{m}$  p  $\text{In}_{0.68}\text{Ga}_{0.32}\text{P}$  base, a  $0.05 \mu\text{m}$  p+  $\text{In}_{0.68}\text{Ga}_{0.32}\text{P}$  back surface field, and a  $0.04 \mu\text{m}$  n  $\text{Al}_{0.33}\text{In}_{0.67}\text{P}$  window layer. We have thinned the top cell in the current junction cell. A p++/n++ AlGaAs/InGaP tunnel junction structure has been incorporated in the dual-junction cell. All of the dual-junction cell structures were grown on GaAs substrates.

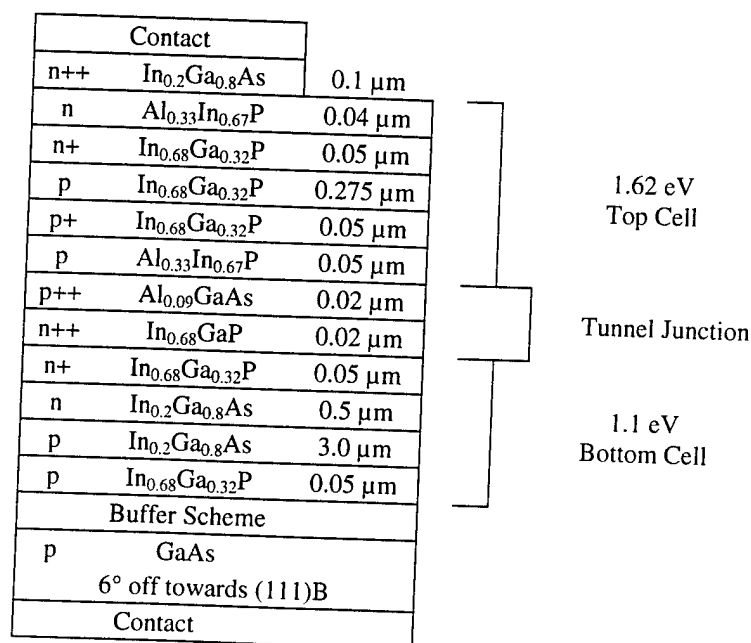


Figure 1.—Epi-layer structure of the 1.62 eV InGaP/1.1 eV InGaAs dual-junction cell.

## **WORK TO BE PERFORMED DURING THE NEXT REPORTING PERIOD**

During the next reporting period, the emphasis will be on processing of the thinned dual-junction cell with the new tunnel-junction configuration, followed by testing under 1 to 20 sun concentrations. The cell structures and processing parameters will continue to be optimized to realize the highest possible efficiency values under concentrator conditions. However, it appears likely that we will need to request a no-cost extension of the program by three months, to bring it to a successful completion.

---

***Cost and Completion Estimates***

---

The current costs have been calculated and the estimates are as follows:

- Total Costs (cumulative) through March 22, 2001 ..... \$ 150,930
- Estimated Costs for the following quarter..... \$ 50,000
- Estimated Costs to the contract completion ..... \$ 149,056
- Estimated physical completion through March 22, 2001 ..... 51%